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ECOSYSTEMS

Socioeconomic Mechanisms Preventing Optimum Use of Ecosystem Services: An Interdisciplinary Theoretical Analysis

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Abstract

Ecosystems provide a wide range of services to society. Some forms of use affect the quality of the ecosystem, reducing its value for other users. This leads to a conflict of interest that is often settled through political processes, resulting in some form of regulation. We link theory on ecosystem response to theories from the socioeconomic branches of science to analyze the mechanisms behind two widespread problems associated with such political solutions. First, they often represent a compromise rather than an integrative solution. We demonstrate that, particularly in sensitive ecosystems, integrative solutions yield a higher average social utility and imply a higher ecosystem quality. Integrative solutions require insight into ecosystems responses to different forms of use and a complete overview of ecosystem services to society. Second, there is a systematic bias away from optimal shared use toward activities that are detrimental to ecosystem quality. This bias arises from the fact that utilities depending on ecosystem quality are often shared by large diffuse groups, whereas pollution and harvesting activities can usually be traced to relatively small and well-organized groups. Theory and data indicate that this type of concentrated group is systematically better at mustering political power than large groups, which find it difficult to realize collective action due to what is known in game theory as "free-rider problems."

Our analysis suggests that the following three key ingredients are needed to correct the problems of bias and compromise: (a) clear insight into ecosystem dynamic responses to human use, (b) a broad inventory of credible measurements of ecosystem utilities, (c) avoidance of bias due to differences in the organizational power of groups of stakeholders. We argue that good ecosystem models, institutionalized ecosystem valuation, and innovative tax-setting schedules are essential to achieving a socially fair and sustainable use of ecosystems by societies. In addition, we highlight the fact that many environmental problems remain unresolved for a long time and briefly identify the social mechanisms responsible for this delay.

Key words: ecosystem; utility; tax; model; welfare; stakeholders; lake; resilience; collective action; hysteresis.

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Introduction

Ecosystems are usually of importance to several different groups in human societies ("stakeholders"). Lakes, for instance, can be used by industries to get rid of waste water, but they can also be used by swimmers who want clean water and by fishermen who prefer certain kinds of fish. Also, the lake water may pass through rivers and other lakes before ending up in the ocean, affecting many more distant stakeholders along the way. Since some ways of using the ecosystem services tend to lower the quality of the system for other users, there is often a conflict of interests. If one regards human interests as paramount, policy makers would ideally strive to maximize the total utility obtained from a given ecosystem to serve society as a whole. In this paper, we explore that idea and analyze the influence of socioeconomic dynamics on the outcome of attempts to achieve this theoretical optimum. Obviously, any analysis of this problem requires an insight into the response of ecosystems to different types of human use, as well as an understanding of socioeconomic dynamics and their effect on the ecosystem.

One widely recognized barrier to the development of an integrative theory is the current segregation of the scientific disciplines that analyze ecosystems dynamics from those that analyze economics and social interactions. Indeed, in our experience, it is not only the jargon and methods, but even the perception of "what drives this world" that divides these disciplines. This paper is the product of the cooperation of scientists working in three different disciplines: ecology (M.S.), economy (W.B.), and sociology (F.W.). We have attempted to link the insights from each of these branches of science that we consider essential for an understanding of the problem of the shared use of ecosystems by various societal groups. The results highlight various aspects that have been largely ignored by both economists and ecologists (for example, Clark 1990, and many others) in the existing literature on dynamic ecosystem management.

In the first section, we note that various ecosystems tend to respond nonlinearly to stress increases resulting from human use, a fact that has important implications for the interaction of ecosystems with socioeconomic systems.

In the next section, we address the theoretical question of how to use ecosystems to maximize benefits for all different users. This type of problem is addressed by normative economics, a version of which assumes that all kinds of interests can be usefully expressed in a common currency (Harberger 1974). In practice, this is a formidable task with many difficulties. Indeed, the best minds in social science have struggled with this problem (Sen 1999). We have nothing to add to this discussion and will take a utilitarian approach here. Even more complex, however, than solving the question of what should be done is the problem of unraveling the mechanisms that determine what actually is done. The dynamics of societies depend on economic and political interactions, and ultimately on the behavior of individuals who respond to their environment in much more complex ways than can be captured by the basic rules of economy and politics. The literature on this problem covers a wide range, from plain economic motives to beliefs and ethics.

In the third section, we review the theory on the economic aspects of this range, known as "positive economics" or "political economics." In this approach, economic analysis is used to measure and predict the political strength of a coalition of common-interest stakeholders.

In our final discussion, we reflect on the main conclusion and the limitations of the approach.

Ecosystems Response to Human Use

Ecosystems are tremendously complex and quite unpredictable in their response to human activities. Furthermore, they differ widely in terms of species composition, potential services to society, and threats to their resilience. In view of this idiosyncrasy and complexity, any attempt to review their potential response to human use in a single section of a paper may seem futile. However, we think that with respect to the search for strategies for sustainable use, there is at least one aspect that deserves special attention because it is very important and can be treated in a rather generic way—namely, irreversibility and hysteresis in the response of ecosystems.

Early work showing how fisheries and grazing systems may collapse when they are overexploited has become well known. However, ecologists in different fields are gradually discovering that a multiplicity of stable states and the resulting nonlinearity of responses to change in conditions may be the rule rather than the exception in a wide class of ecosystems (for example, DeAngelis and others 1989; Holling 1973; Ludwig and others 1997; Rietkerk and others 1997; Walker and others 1981; Hanski and others 1995; Carpenter and Pace 1997; Case 1991; Lertzman and others 1994; Scheffer and others 1993; Tilman 1982). It is important to note that catastrophic response in a certain class of eco-

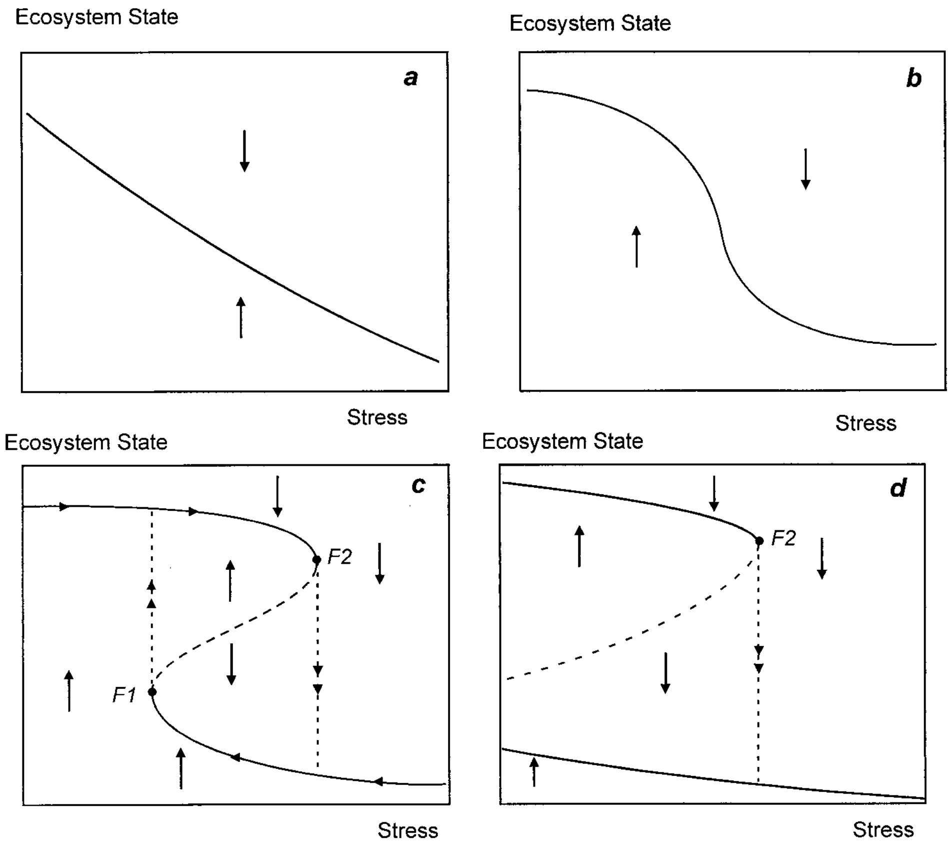

Figure 1. Schematic representation of possible responses of ecosystems to stress imposed by human use. The lines represent equilibrium states. The arrows indicate the direction of change when the system is out of equilibrium.

systems is usually due to a single dominant feedback mechanism. As a result, we believe that, in addition to being highly relevant, catastrophic change is often relatively easy to understand and predict, unlike gradual changes in structure, composition, and biodiversity. In this section, we briefly sketch the range from smooth to catastrophic responses that can be found in ecosystems, focusing on the latter in view of the thorny consequences for sustainable use. The case of shallow lake eutrophication serves as an example. This simple model will be used in the subsequent sections to discuss the implications of such nonlinearities for human–nature interactions.

Irreversibilities and Hysteresis in Ecosystems

It is often assumed that impact will tend to increase more or less smoothly with intensity of use. However, accumulating evidence indicates that the response to increasing stress is frequently far from smooth. Indeed, the ecosystem may often appear to be untouched by increasing stress until it suddenly collapses when certain threshold values are surpassed. To clarify differences in the way in which an ecosystem may respond to changing conditions, we can represent the response in simple graphs that plot the ecosystem state as a function of the stress imposed by human use (Figure 1). For simplicity's sake, these hypothetical graphs consider only one state variable and one stress factor. Obviously, this is a rather minimal representation of the response of ecosystems to human impact. Nonetheless, it serves to illustrate the points we want to make in our analysis.

The unidimensional representation of state seems a strong simplification at first sight. However, much of the essence can often be captured by a single variable, because in a given type of ecosystem, many aspects of the system's state tend to shift in concert with a few important key state variables. Examples of such key state variables that could be represented by the vertical axis are total plant biomass per unit area or turbidity of lake water. Clearly, many more aspects of ecosystem state are of importance to human users, and even more factors are essential for the functioning of the systems. For instance, in shallow lakes, quality of the fish stock, occurrence of toxic algae blooms, biodiversity, and turbidity may all be of interest to different groups of users; in addition, zooplankton biomass and species composition may be essential to the

ecosystem's functioning. A stress to the system, such as overloading the lake with phosphorus, will affect all of those characteristics, but changes tend to follow the same coherent pattern in most lakes. Therefore, the value of one key variable, such as turbidity or phosphorus sequestered in algae (Carpenter and others 1999), may be used to roughly reflect the general state.

"Stress" is the general term we will use here to describe the effect of human use. The human use of nature can be through harvesting or destroying biomass (for examples, rainforest harvest, fisheries, cattle ranching), but much of the impact may also be due to stressing the system by affecting its abiotic conditions (eutrophication, groundwater level reduction, climate change). The horizontal axis of the figures may be thought of as representing any of these stress factors.

The state of some ecosystems may respond in a smooth, continuous way to increasing stress (Figure 1a), but more often the system remains relatively inert over certain ranges of conditions and then responds more dramatically when that stress approaches a critical level (Figure 1b). A crucially different situation arises when the response line is folded backward (Figure 1c, d). This is known as a "catastrophe fold" and implies that the ecosystem has two alternative stable states over a range of environmental conditions. The explanations and consequences of this scenario are discussed more extensively in the next section, but in short it implies that when the ecosystem is in a state on the upper branch of the sigmoid response curve, it will not pass to the lower branch smoothly. Instead, when increasing human use has altered the conditions sufficiently to pass the threshold (*F2*), what follows is a "catastrophic" transition to the lower branch (vertical line with double arrow). Note that when one monitors the system prior to this switch, little change in its state is observed. Indeed, such catastrophic shifts typically occur quite unannounced, and early warning signals of approaching catastrophic change are difficult to obtain.

Another important feature of the response of such catastrophic systems is that in order to induce a switch back to the alternative state on the upper branch, it is not sufficient to restore the stress level that occurred before the collapse (*F2*). Instead, one needs to go back much further, beyond the other switch point (*F1*), where the system recovers by shifting back to the upper branch. It may be possible that the threshold level for a forward switch, but not that for the backward switch, is within the range of conditions that may be easily influenced by humans (Figure 1d). Desertification in some xeric areas is an example (Rietkerk and Van de Koppel 1997). An increase in grazing intensity can destroy vegetation; but when conditions are sufficiently dry, erosion, sunburning of seedlings, and lack of capacity to retain soil water may prevent recolonization by plants even if all grazers are removed.

Since catastrophic changes from one stable state to another have serious implications for the dynamics of ecosystem use, we pay extra attention to systems with this property in our review. The theoretical possibility of catastrophic switches in ecological systems has long been a topic of interest (May 1977). Examples include lakes (Carpenter and Pace 1997; Scheffer and Jeppesen 1998) dessertification (Noy-Meir 1975; Walker and others 1981), and various grazing systems (Van de Koppel and others 1997). A simple mathematical model for the behavior of systems with catastrophic shifts between alternative stable states is presented in Appendix 1. Here we briefly describe the insights obtained from studies of shallow lakes in The Netherlands, which will serve as the main example throughout the paper.

Shallow Lakes

Many of the shallow lakes and ponds situated near populated areas have become murky as a consequence of eutrophication resulting from the use of fertilizers on the surrounding land and an increased inflow of waste water from human settlements and industries. Although some deeper lakes have recovered quite well in response to eutrophication control programs, many shallow lakes have shown little improvement despite large investments. In fact, even when the nutrient load is reduced to values well below those at which the collapse of the clear and vegetated state occurred, shallow lakes tend to remain in a highly turbid eutrophic state. A positive feedback in the development of submerged vegetation is probably the main explanation. In most lakes, light is likely to be a primary factor in limiting the colonization by submerged plants (Hutchinson 1975; Chambers and Kalff 1985; Vant and others 1986; Skubinna and others 1995). On the other hand, water clarity tends to increase in the presence of plants (Schreiter 1928; Canfield and others 1984; Jeppesen and others 1990; Pokorny and others 1984). As a result there can be two alternative stable states. In very turbid water, light conditions are insufficient for vegetation development; but once vegetation is present, the water clears up and the improved light conditions allow the persistence of a lush vegetation (Scheffer 1989; Scheffer 1998; Scheffer 1990).

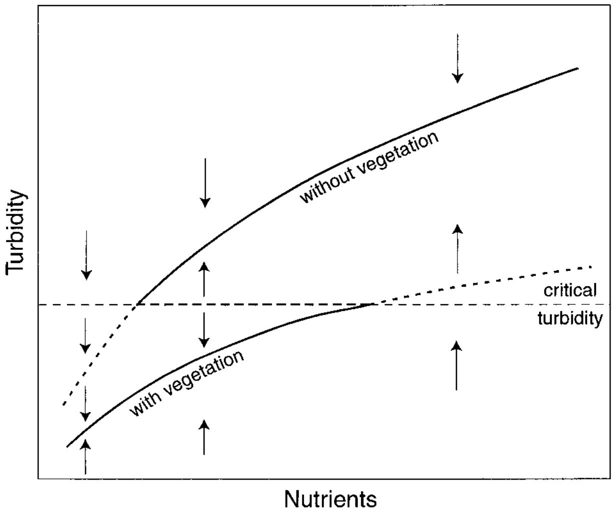

Figure 2. Graphic model for alternative stable states in shallow lakes.

At first, the argument that lake ecosystems will have alternative equilibrium states may be convincing. However, demonstration of stabilizing mechanisms per se is not sufficient to conclude that a lake has alternative stable states. Although relatively complex mathematical models are needed to capture the dominant mechanisms that are involved, a very simple graphic approach suffices to illustrate the main point in the shallow lakes case (Figure 2). The graph is based on three assumptions: (a) turbidity increases with the nutrient level; (b) vegetation reduces turbidity, and (c) vegetation disappears when a critical turbidity is exceeded.

In view of the first two assumptions, equilibrium turbidity can be drawn as two different functions of the nutrient level: one for a plant dominated situation, and one with a systematically higher turbidity for an unvegetated situation. The third assumption translates into a horizontal line representing the critical turbidity for vegetation survival. Above this line, vegetation will be absent, in which case the upper equilibrium line is the relevant one; below this turbidity, the lower equilibrium curve applies. The emerging picture shows that over a range of intermediate nutrient levels, two alternative equilibria exist: one with clear water and aquatic plants, and a more turbid one without vegetation. At lower nutrient levels, however, only the macrophyte-dominated equilibrium exists; whereas at the highest nutrient levels, there is only the turbid equilibrium without vegetation. If the lake is in a clear state (on the lower branch of the graph), an increase of the nutrient level will lead to a gradual and moderate rise in turbidity until the critical turbidity for plant survival is reached (horizontal line). At this point, vegetation collapses and the lake "jumps" to the turbid upper branch. Reduction of nutrients after this catastrophic transition does not result in a return of plants until the critical turbidity is reached again.

However, note that this backward switch happens at a much lower nutrient level than the forward switch. Thus, often, reduction of the nutrient level to values at which the lake used to be clear and vegetated will not lead to restoration of that state. This is indeed the experience of many lake managers. The essence of the explanation is that in the absence of the clearing effect of vegetation, the water remains too turbid for vegetation to return. This simple graphic model is analogous to the smooth sigmoidal catastrophe fold shown in Figure 1c. The intuitively traceable lake example allows one to get a feel for the way in which such catastrophic responses may arise. Clearly, the graphic model is a rather extreme simplification of the functioning of lake ecosystems. However, more elaborate mathematical models and analysis of the behavior of many lakes confirm the main result: shallow lakes may have alternative stable states over a certain range of nutrient levels (Scheffer and Jeppesen 1998).

One may get a better intuitive feel for the implications of such alternative stable states from stability landscapes of the system (Figure 3). The bottom plane of this composed figure shows a line that indicates how turbidity increases with the nutrient level. The interpretation is analogous to that of the main sections of the previous graph (Figure 2). The middle part of the folded line represents the critical turbidity for plant survival. The two outer sections represent the clear and the turbid state. The five subsequent hilly landscapes in the figure representing stability landscapes show the equilibria and their stability at five different nutrient levels. The system, like a rolling ball, will be attracted to the valleys. These correspond to stable parts of the folded curve on the bottom plane, whereas the hilltops represent the threshold turbidity corresponding to the dashed middle section of the curve. The front landscape represents a situation with heavy nutrient loading in which just one equilibrium exists, a turbid one, whereas the rear picture represents the pristine state of a lake, a low-nutrient situation in which a clear water equilibrium is the only possible stable state. Between these two extremes, there is a range of nutrient levels over which two valleys, and hence two alternative stable states, exist.

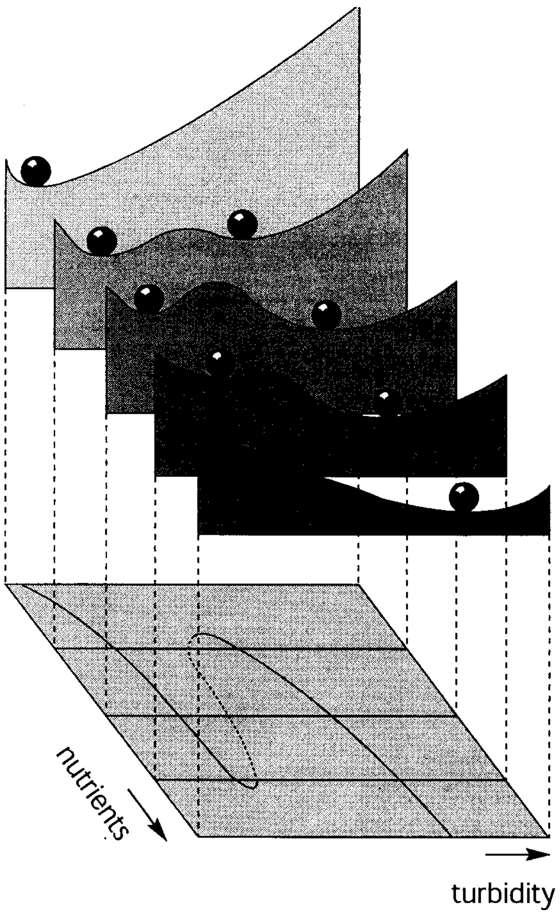

Figure 3. "Marble-in-a-cup" representation of the stability properties of lakes at five different levels of nutrient loading.

The response of a lake with such properties to eutrophication and subsequent restoration efforts can be easily understood from this representation. Starting from the pristine state, a moderate increase in nutrient level gives rise to an alternative turbid valley, but if no large perturbations occur, the lake will stay in the clear state. Continuing enrichment, however, gradually causes the size of the clear valley to shrink to nil, making the lake more and more vulnerable to perturbations, such as storms or plant kills, which can bring the system across the hill to the valley of the turbid state. However, even in the absence of perturbations, the period in which the lake stays relatively clear despite nutrient loading will finally end with a catastrophic transition into a turbid state as the valley around the clear water state disappears. Attempts to restore such lakes by reduction of the nutrient level often have little effect, since the system tends to stay in the turbid valley of attraction.

Social Optimum in the Shared Use of Ecosystems

Stakeholders and Their Welfare. One approach in economics to finding the best solution for society as a whole is to express all interests in a common currency (in practice, money) reflecting something termed "welfare" or "utility," which is measured using principles expressed in Harberger (1974) and Wilson (1992). In the case of lakes, stakeholders whose welfare is related to use of the ecosystem may be:

- Farmers who allow nutrients from cattle dung and fertilizers to pollute the water in the catchment area of the lake. Reducing such diffuse pollution has a cost for the farmers. Thus, this use of the lake has an economic benefit for them.
- Households (or municipalities) and industries that drain their waste water into the lake. Reduction of pollution from such point sources also has a cost that increases with the required level of cleaning.
- Recreational fishermen, swimmers, boaters, bird watchers, owners of homes bordering on the lake. These users require that a certain basic quality be maintained for the water and its associated ecosystem.
- Hotels, campgrounds, restaurants, and so on, that serve recreational users. Their income increases with the number of recreational users attracted by the lake.
- Drinking water companies that use lake water as a source. Cleaner water is cheaper to process than polluted water with toxic cyanobacteria.
- Users of the chain of rivers, lakes, and oceans that receive water from the outflow of the lake.

Obviously, estimating the welfare functions that describe how the welfare of each stakeholder changes with its use of the lake is not simple. Although there are various techniques that yield reproducible results for valuating different ecosystem services, the topic is still controversial (Portney and others 1994). It will probably always be difficult to express the value of these highly diverse aspects in a common currency. Also, one may argue whether the maximization of the value for human use, rather than other ethical standards, should be the criterion of choice. Nonetheless, the valuation approach is, in our opinion, a great step forward compared to the current practice, in which many obviously important values of ecosystems are simply not considered in the policy-making process.

To clarify, and to avoid a long debate on this

controversy, imagine that the lake and its watershed are owned by a single entity (for example, a monopolist) and operated like a park or a public utility where the objective is to design pricing schemes (Wilson 1992) that maximize every possible dollar of value that can be squeezed out of the variety of services provided by the lake and its watershed. For example, potable water could be sold to cities from the watershed itself, provided that the watershed was kept clean enough for human consumption. Recreational, scenic, boating, fishing, and other services could be packaged in this imaginary world, much like the packaging of park rides or services offered by a public utility. Admission fees could be charged to visitors to the area, and rental fees could be levied on living units within the area. The monopolistic owner would have an incentive to maintain the lake and its watershed in such a way as to maximize the total sum of these values and might not sell any loading services at all to agriculture, developers, leaking septic systems from cottages, and so on. The owner would charge leakage fees to any cottage owner whose septic tank leaked into the lake, as well as loading fees to the farmers.

The park or public utility paradigm can help to clarify our thinking about the myriad of services that a lake and its watershed generates and the skills that a monopolistic operator needs to extract the maximal value from the spectrum of services. This way of seeing the problem might help to avoid nonproductive debates about the merits of utilitarianism and problems with benefit/cost analysis, and to focus the discussion on how society might measure and extract all potential values out of the bundle of resources comprised by a lake and its watershed. The practical problem of delivering clean water to New York City is discussed by Chichlinisky and Heal (1998). We urge the reader to look at this case as a prototype for the design of a watershed clean-up program and an institutional framework that can get the job done.

A Graphic Theory of Ecological Limitations to Shared Use. In a society comprised of different interest groups, the situation is obviously more complex. As a first approach, we introduce the concept of a hypothetical Rational Social Planner (RASP), which replaces the monopolistic park owner of the previous example. We will use this concept to show more specifically how the trade-off of different lake uses might work. Our hypothetical RASP knows how the welfare of each stakeholder is related to its use of the lake and therefore should be able to decide what combination of uses would yield the highest per capita welfare. However, to do this, the RASP needs to take into account how some uses of the system affect the value for others (for example, swimming is incompatible with algae bloom). Therefore, it is crucial that the RASP also knows how the system changes in response to its exploitation. Thus, it is the combination of the ecosystem response with the welfare functions that serves as a basis for the RASP to find the integrated use that yields the highest welfare for society. To illustrate the principle of maximizing welfare using knowledge of the constraints imposed by the functioning of the ecosystem, we will return to the response graphs (Figure 1) presented in the previous section. In these figures, the horizontal axes represent conditions, such as nutrient loading, that are affected by human use. There is usually a clear economic benefit related to such use. If we assume that the intensity of human use increases along the horizontal axis, the economic benefit, and hence the welfare of the users, will increase along this gradient. The precise relationship will depend on the specific situation, but the increase of welfare will usually diminish at very intense use. In the following discussion, we will call users that significantly affect the state of the ecosystem "Affectors" for short.

The vertical axes represent an aspect of the state of the ecosystem, such as plant biomass. Most components of the ecosystem tend to change in concert, and the variable depicted on the vertical axis merely serves as an indicator of the overall state. There can be many uses of an ecosystem that depend on its state but have little effect on it. For instance, swimming and bird watching are better in clear lakes and have little effect on lake ecology. Also, ecosystems may provide services to a wide group of more distant stakeholders that depend on the state. For instance, in shallow lakes, vegetation helps to purify the water through natural processes such as denitrification. Many downstream inhabitants will enjoy the benefits of the clean water that flows from the lake into the river system and eventually into the ocean. In the following discussion, we will call users that benefit from the system but do not significantly affect the state of the ecosystem "Enjoyers" for short.

In most cases, the ecosystem's value for Enjoyers will diminish with increasing exploitation by Affectors. Thus, in the graphs (Figure 1), the low level of the system's state indicator at high exploitation will correspond to the lowest value for Enjoyers, and the welfare that Enjoyers can obtain from their use of the ecosystem will increase systematically with the level of the state indicator represented by the vertical axis.

Obviously, many more groups of stakeholders

exist in practice, and their interests are often overlapping rather than strictly complementary as in this Affectors–Enjoyers model. However, this distinction is useful for a first exposition of the ideas. We thus assume that overall community welfare obtained from the ecosystem is simply that of the Affectors plus that of the Enjoyers. Total welfare will therefore increase along both axes used in the ecological response graphs (Figure 4). If nature imposed no restrictions, the highest welfare could be obtained by combining maximum exploitation with a maximum value of the ecosystems state indicator. However, the state is a function of the exploitation. Hence, the response of the ecosystems limits the possible combinations of use by Affectors and Enjoyers to points on the stable equilibrium lines in the response graphs (Figure 1). Projection of these lines on the welfare plane (Figure 4) shows in one picture what stable combinations of use by Affectors and Enjoyers are possible, as well as depicting their associated welfare (see Appendix 2).

Bad Compromises and Risky Optimum Solutions. This information allows the hypothetical RASP to guide society in its use of the ecosystem. The highest point on such graphs represents the maximum overall welfare that a society of stakeholders can achieve. Mostly, it will be good for society to move as close as possible to such a maximum. Depending on the precise shape of the ecosystem response curve, there may be a single optimum (Figure 4a, curve I) at an intermediate stress level indicating that a compromise between Affectors and Enjoyers yields the highest overall welfare, or two local optimum points (Figure 4a, curve II) representing biased situations that maximize the welfare of either Affectors or Enjoyers. The latter observation is important because it shows that a compromise (which is often the outcome of sociopolitical processes) may well be a bad solution, because it represents a situation with low overall utility. Curve II in our example, which results in this situation represents the response of a sensitive ecosystem. Even low levels of stress result in extensive deterioration of the state. The reason that a simple compromise yields low overall welfare in such situations is intuitively straightforward. Even a low stress level (yielding low gains for Affectors) produces a large loss for Enjoyers. If the ecosystem can be treated in separate spatial units (for example, if many lakes exist in an area), the obvious solution may be to assign some units entirely to Enjoyers and others entirely to Affectors. This kind of compromise problem has been worked out in more detail for the management of aquatic vegetation, which is considered a desired feature of lakes by some users but regarded as a nuisance by others (Van Nes and others 1999).

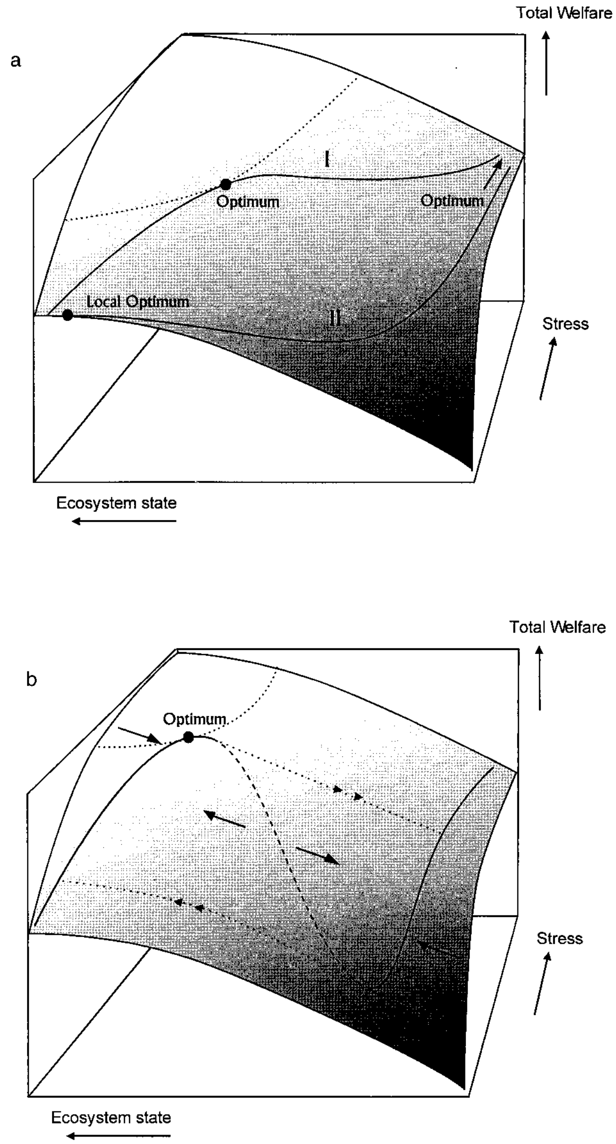

Figure 4. Graphic model showing how a theoretical society of Enjoyers and Affectors may obtain optimal welfare from use of an ecosystem. The welfare of Enjoyers increases with the ecosystem state indicator, whereas the welfare of Affectors increases with the level of stress imposed on the system by their activity. Thus, total welfare will increase as indicated by the plane. The curves on the plane indicate how the ecosystem state responds to the imposed stress (as in Figure 1). The optimum social welfare compatible with ecosystems dynamics is therefore obtained at the highest point of each curve.

Figure 4b shows what happens if the response of the ecosystem is catastrophic (Figure 1c, d). In this case, the maximum utility tends to be close to the threshold at which the system collapses. The reason

is that in such ecosystems, stress typically has little effect due to the stabilizing feedbacks that tend to keep the system in the same state, until stress has increased enough to bring the system close to the border of collapse. Therefore, Enjoyers will be well off until quite high levels of stress are imposed on the system. This implies that aiming for the maximum welfare may be a hazardous strategy, because a slight miscalculation of the RASP or some environmental variability (for instance, an exceptionally hot year) may easily induce a switch to the lower branch of the curve representing an alternative stable state with a low overall utility. In order to restore the system, the stress level has to be reduced to quite low values (at the cost of a considerable further loss of total welfare) before a switch back to the other branch occurs. This implies that for societies that use ecosystems with multiple stable states, it may pay in the long run to be conservative in their ecosystem management strategy. This aspect is analyzed in some depth by Carpenter and others (1999).

Note that the total welfare of a group depends on the welfare of individuals in that group multiplied by the number of individuals in that group. Thus, if, for instance, the proportion of Affectors decreases relative to that of Enjoyers, the stress-dependent welfare should be down-weighted. In terms of Figure 4, this would imply that the welfare plane is tilted, and the optimum welfare will be further away from the critical threshold. Indeed, in societies where the enjoyment type of nature use becomes more important, overall utility will benefit from an even more careful use of its surrounding ecosystems.

However, a regulating authority will usually respond to political pressure from Enjoyers and Affectors rather than seek the real social welfare optimum. The nature of the political pressure depends not only on potential individual welfare gains and the size of different interest groups, but also on other socioeconomic aspects that determine the political power of groups. Industries and other types of Affectors are often more effective in exerting political pressure than Enjoyers, among other reasons because the latter tend to be more widely scattered. As a result, politics tend to distort the picture, and an authority seeking to balance political pressure from Enjoyers and Affectors will be biased away from the social optimum in the direction of further deterioration of an ecosystem.

In the following sections, we use the lake example to highlight several socioeconomic theories about the factors that facilitate or prohibit societies from obtaining the theoretical optimal utility from ecosystems. A formal mathematical framework of these theories is presented in the appendices.

Naive and Smart Ways for Approaching Optimum Utility. Obviously, in reality, an ideal RASP does not exist to oversee the entire system. In the worst case, a management authority that tries to maximize community utility from the ecosystem may actually know nothing about the dynamics of the overall system. In that case, one might imagine that the authority would follow a simple iterative "hill-climbing" strategy to optimize overall utility. The minimum requirement is that the authority can somehow measure the utility that different groups (Affectors and Enjoyers) obtain from the lake. This can be done, for instance, by measuring the "willingness to pay" for different aspects. If the authority continuously monitors the rise and fall of utility for different groups, it can iteratively adjust regulations on pollution in such a way that total utility increases (see Appendix 2). For instance, if a small increase in the pollution load results in an increase of total utility, the regulating authority will allow a small further increase; whereas in the case of an observed decrease in utility, it will reduce the allowance a bit. This hill-climbing strategy results in a gradual iterative movement to increasingly higher utility and can thus guide society to an optimum utility, as indicated in Figure 4.

Apart from the question of whether this approach is feasible in any practical situation, there are several fundamental caveats to this approach to finding optimal utility. First, in a system with alternative stable states, the optimum tends to be close to the threshold at which the system collapses. Since in reality the authority will never be absolutely accurate, it may well accidentally allow the system to go beyond the "flip," which is a little beyond "Optimum" on the diagram, causing the lake to switch to the "bad" state. Second, after this crash, the hill-climbing method guides the authority further up along the lower branch, allowing progressively higher pollution to the advantage of the Affectors but not that of overall welfare. In order to move to the more desirable utility optimum on the "good" branch of the curve, after the crash, society would need to move temporarily "downhill" (that is, to a further decrease in overall welfare) until it reaches the point where the lake recovers to the upper branch to come back to the optimum.

Obviously, it would be much better if the authority had some insight into the rules that govern the ecosystem dynamics and adjusted its policy in a cautious way so as to minimize the chance of letting the ecosystem and its utility for society collapse.

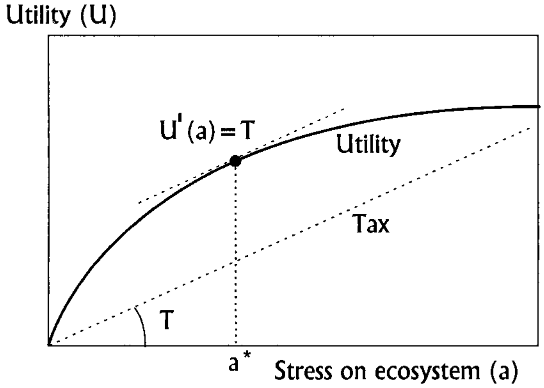

Figure 5. Tax as a way to reduce stress (a) imposed on the ecosystem by the activity of Affectors to a desired level a*. If the Affector optimizes his/her net benefit (U(a)–Ta), he/she will tune his/her activities to the point where the first derivative of the utility curve equals the tax rate $U'(a) = T$.

There are many ways in which authorities can regulate, but in practice, taxation or some kind of user charge is a popular instrument. The idea behind taxation as an incentive is that given the tax rate Affectors will choose their pollution load in such a way that they maximize their individual net benefit, taking both tax and gains into account. Since the gains usually will not keep increasing at a constant rate with the intensity of the Affectors activities and the resulting pollution, a fixed tax rate per unit of pollution will lead a rational Affector to keep its pollution activities to a certain predictable level (Figure 5). Theoretically, an authority with a sufficient understanding of the system can thus set the tax rate in such a way that Affectors realize precisely the level of pollution that leads to the social welfare optimum (see Appendix 3).

One can easily derive a tax-setting scheme that would allow a society to follow the hill-climbing procedure described in the previous section (see Appendix 3). However, this hill-climbing approach is rather limited. If the system has multiple equilibria or several local welfare maxima, one needs a deeper insight into the ecosystems dynamics. Using this insight, the authority may want to levy a temporary surtax to lower pollution for a long enough period of time to allow the lake to flip to the "good" branch. The surtax could then be lifted. This is something like placing a quantity control on the Affectors to guide them toward the right basin of attraction, and then imposing a tax to guide them toward the right level for that basin. It is beyond the scope of this paper to discuss the design of such elaborate decentralized regulation schemes. The general theory of mechanism design (Wilson 1992; McAfee and Reny 1992) should be useful for the design of more elaborate regulatory mechanisms that have good incentive properties and minimize costs of implementation and administration (see also Brock and Evans 1986).

Mechanisms Preventing Optimum Use

In practice, the forces that drive societies do not naturally approach an optimum welfare situation. Positive economics, as opposed to normative economics, deals with the problem of analyzing these forces. The basic assumption is that each individual will try to maximize its welfare by "playing its cards in the smartest way." Game theory is the standard tool used for computing strategies that individuals (or groups) would choose on the basis of their prior assumptions on how other individuals (or groups) will respond to problems. Quite often, the tendency to tune behavior to such prior assumptions results in suboptimal situations from the viewpoint of social welfare. As an environmental example, consider the case in which two individuals (or cities or countries) use the same lake (or ocean or atmosphere). Each one expects that the other will adjust its behavior to prevent the ecosystem from deteriorating. However, precisely for that reason, each one will have less incentive to adjust its own behavior, and the system is more likely to deteriorate.

In the following discussion, we will further elaborate our Affector vs Enjoyer example to show how this type of theory can be applied to the analysis of forces that determine which interest groups are more powerful in forcing policy in a desired direction.

Pollution Is Profitable: The CCPP Phenomenon. One well-known problem in environmental protection is known as the "CCPP phenomenon" (Communize the Cost, Privatize the Profit) (Hardin 1993). In an unregulated situation, Affectors benefit from their activities while the costs resulting from a deteriorated ecosystem state are carried by the Enjoyers. In the common situation where Affectors are also partly Enjoyers of the same ecosystem, the costs of the activities may be considered to be borne by to the community as a whole, whereas the profit from the affecting activity goes exclusively to the Affectors. This imbalance is at the core of many environmental problems. In the absence of any feedback, Affectors may keep increasing the stress on ecosystems, even if the profit associated with further increase is very small. In this type of saturated utility situation, even a slight tax on stress-inducing activities could have a large effect. A fair tax system as sketched earlier would ideally force Affectors to

take real environmental costs into account, typically inducing a large reduction in the stress imposed on the ecosystem. However, if there is no RASP and there are no regulations yet for this particular Affectors activity, the first step toward establishing a more fair situation from a social point of view is to mobilize the forces of the Enjoyers in order to change the policy. Game theory models suggest that the political pressure mounted by groups such as Enjoyers and Affectors depends strongly on their ability to overcome so-called collective action problems.

The Collective Action Problem and its Effect on Politics The essence of models that address collective action problems is easy to understand. Suppose a tax T on pollution is proposed by the regulatory authority as a trial balloon. Affectors will want to invest their resources to exert political pressure against this policy. The amount of effort will depend on their beliefs about the impact of their total contributions on the chances of this policy actually being implemented. However, each Affector also has an incentive to free-ride on the contributions of his comrades in the common effort to stop passage of T by the authority. In practice, an Affector will tend to contribute less than he/she should if he/she believes that his/her comrades will invest properly.

We can model this specific case as a simple noncooperative game where each Affector forms his/her beliefs based on the actions of the other Affectors and chooses his/her contribution level in such a way that it maximizes his/her expected gain given his/her prior beliefs. It is easy to show that in such models contributions in equilibrium increase as the stakes are less evenly distributed over the players (Magee and others 1989, Appendix to Chapter 6, p. 278–90). This makes sense because if the losses were all concentrated on one large Affector, he/she would not face a free-rider problem and would optimize his/her effort against the policy, whereas if there were two even-sized Affectors, each would tend to free-ride on the other's efforts. A similar free-rider analysis can be applied to the Enjoyer side of the political struggle.

In some situations, if the regulator is a management agency, a pressure analysis using game theory may approximate what actually goes on in practice. However, it should be stressed that such noncooperative Nash equilibrium modeling is not always appropriate. In a repeated situation where the Affectors are interacting on a face-to-face basis, other more adequate models have been proposed (Ostrom and others 1994; Frank's 1992 review of Coleman 1990). Still, in practice, social interactions tend to be much more complicated than those incorporated in such models.

Total political pressure from an interest group depends, among other things, on the tendency of their members to free-ride on the efforts of other group members and their belief in the effectiveness of the overall pressure. Political-pressure supply functions may be derived as Nash equilibria from a noncooperative game model following Magee and others (1989, Appendix A.6.5, p 287). Their analysis suggests that the resources invested by an individual to exert political pressure depend on the interest at stake, but also on what has been termed "perceived effectiveness and noticeability" (Magee and others 1989). A mathematical treatment can be found in Appendix 4, but the idea is intuitively straightforward. The perceived effectiveness depends on the strength of beliefs in the power of the sum of contributions to move policy in the direction desired by the Enjoyers. This will increase along with the merit of the Enjoyers' case. However, noticeability, and hence the eventual individual effort, decreases along with group size due to the free-rider problem (Figure 6). This is because, all else remaining equal, the larger a group, the more anonymous each member tends to feel. Hence, self-interest is likely to lead each individual in a large group to shirk the duty of contributing a fair share to the group effort.

The decrease in individual effort with group size depends upon how effective the group is in making each member feel "noticeable," so that he/she pulls his/her own weight in the joint effort of exerting pressure. Its efficacy depends on the forces that determine how well a group can muster a collective effort in a situation such as mustering political pressure that serves its common good (Ostrom and others 1994; Putnam 1995).

For example, if the Enjoyers are dominated by recreational businesses and these businesses have a formal organization of longstanding tradition, such as a recreational businessmen's association, then the noticeability would be quite large. Each businessman will be monitored by the association and may be punished for contributing less than the standard expected level of effort. The businessmen's association may have built up a relationship with the authority over the years, which might show up in an increase in the perceived effectiveness that each unit of contribution has on policymaking.

Other forces that might act to increase noticeability include the necessity for each member of the group to have access to a commonly shared factor of production (for example, operating room access for a surgeon, access to the common milk distribution

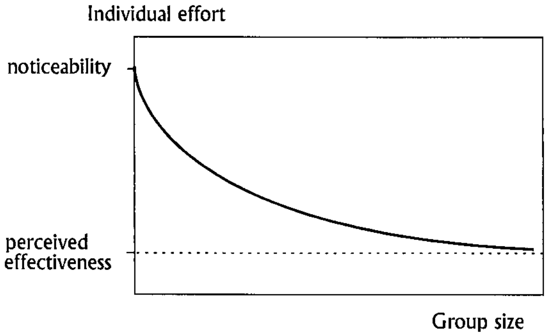

Figure 6. Game theory predicts that an individual's effort invested in political pressure to reach the goal of a political interest group depends on the "noticeability" felt by the group member and the "perceived effectiveness" of the pressure on changing policy in the desired direction. The individual contributions decrease with group size due to an increasing incentive to free-ride on the efforts of others in larger groups, where each member feels more anonymous. Notice that small groups that have a clear case and a social system that reduces free-riding will be politically more powerful than expected from their mere numbers and the welfare at stake.

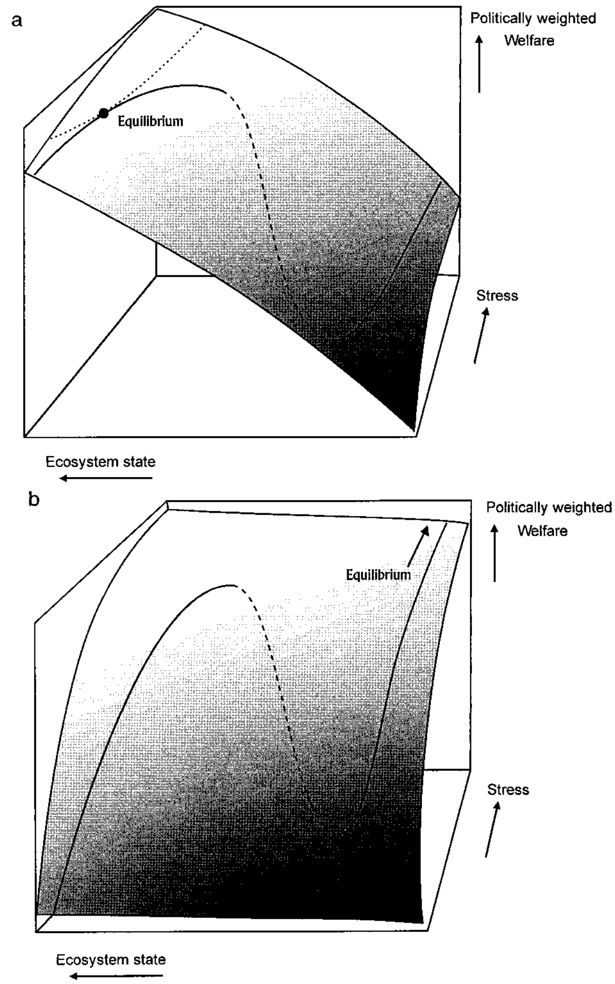

Figure 7. Differences in efficiency at mobilizing political pressure (see Figure 5) distort the process of optimization of social welfare depicted in Figure 4b. The system will tend to an equilibrium in which political pressure from different interest different groups is in balance. If Enjoyers are more efficient (**a**), that equilibrium will be on a more resilient part of the branch representing the desired ecosystem state. However, typically, Affectors are more efficient at mustering political pressure, resulting in a situation (**b**) where the system tends to increasing stress on the ecosystem, even after it has collapsed to the lower branch of the curve.

network for a dairy farmer, access to the docks for a stevedore, access to the multiple listing service for a real estate agent, access to the informal multiple-listing service network based on the goodwill of fellow real estate agents above and beyond access to the formal multiple-listing service for these agents, access to a referral network for a doctor, and so on). The necessity of access to such a factor of production may give a group leverage over the tendency of its members to shirk their responsibility and free-ride.

The repeatability of interactions and density of the communications network within a group (Coleman 1990; Putnam 1995) are key factors that determine the strength of the group to prevent free-riders on collective efforts. Further discussion of the forces relating to the relative efficiency of resolving collective action problems is beyond the scope of this paper.

The graphic models that show how social welfare can be maximized (Figure 4) can be modified to produce graphs that show the expected outcome of political pressure (Figure 7). A formal treatment of the relationship between the two sets of graphs can be found in Appendix 4, but the interpretation is intuitively straightforward. The change of focus is that, rather than seeking the social welfare optimum, the authority that regulates the system is responding to political pressure. Political pressure depends on the interest at stake (that is, the welfare in Figure 4), but also on the effectiveness of the interest group to mobilize forces, which depends on aspects such as noticeability and effectiveness perceived by the members (Figure 6). Therefore, we can obtain a graph that represents the political force that can be applied by Affectors and Enjoyers to obtain a certain utility from the ecosystem by multiplying that utility with a factor that represents the ability of the group to mobilize forces (Figure 7).

In a situation where the Enjoyers are a more coherent and concentrated group than the Affec-

tors, the Enjoyers' political power will be relatively strong. In the case of our example of ecosystems with alternative stable states, this will tend to lead to an equilibrium that is on a relatively safe part of the "good" branch of the equilibrium curve (Figure 7a). The resilience of this situation is relatively high. However, as we have seen, Affectors tend to be better organized than Enjoyers, who are often a large but diffuse group. As a result, the political power of the Affectors is relatively high, resulting in a situation in which there is no local optimum representing a power equilibrium on the "good" branch of the curve (Figure 7b). Instead, the political pressure will drive society further and further up along the branch with low Enjoyer value, due to the high pressure produced for even slight gains of Affector utility.

DISCUSSION

Our analysis of the interactive dynamics of ecosystems and societies has revealed two types of problems that may be crucial to the sustainable and socially fair use of ecosystem utilities. First, ecosystem responses to stress can complicate the choice of management targets and allocation of ecosystem services in complex ways. Second, differences in the ability of social groups to muster political power tend to cause a power bias that results in suboptimal overall utility obtained from the system and a drop in ecosystem quality. Here we review the main points and discuss some complications that could be addressed in further studies.

Compromise vs Integrative Solutions

A first observation from our simple graphic model of the shared use of ecosystems by contrasting groups labeled "Affectors" and "Enjoyers'" (Figure 4) is that sensitive ecosystems may often have two alternative optima for social use. In one optimum, the quality of the ecosystem for Enjoyers is low, whereas the utility from activity that negatively affects its quality is high. In the alternative optimum, quality-affecting activities (and their revenues) are very low, whereas the resulting quality of the ecosystem and hence its utility for Enjoyer groups is high. In such ecosystems, compromise solutions are bad from a overall social point of view; often, a better strategy is to preserve some ecosystems while offering others for intense Affector activities.

To see and realize such solutions, it is obviously essential to understand the response of the ecosystem to increasing stress, but one must also have a good idea of the range of different functions the ecosystem offers for society and the dependence of utilities on the state of the ecosystem. The general observation that better solutions of a conflict of interest often require more effort to analyze and communicate the problem has already been discussed by Mary Parker Follett (1924), who drew the distinction between integrative and compromise solutions. When two people/parties fundamentally disagree as to outcomes, they have a number of options. One can force his/her position and the other accommodate. Both parties can simply walk away from the issue. Or the two parties can seek a way to come to terms. The classic way to do this, according to Follett, is the compromise.

For example, two people in a room are arguing about whether the window should be opened or closed. The compromise is to leave it half open. Compromises have the advantage of seeming fair, but they leave neither party satisfied and so do not generally represent long-term solutions. Integrative solutions are those that go beyond superficial tradeoffs and issues of fairness and seek to find innovative and more longlasting solutions. This is more difficult, because it requires greater patience and deeper understanding of the interests or concerns that both parties bring to the table. Continuing with the example of the window, further exploration of the motives and concerns of both parties may reveal that the conflicting positions (window shut or window open) are due to one person wanting to have air while the other wants to avoid a draft. An integrative solution might be to open a window in an adjacent room. That way both of their basic needs or concerns are met. An integrated solution is better than a compromise, but it takes more work, a greater understanding of the needs of all parties, and more creativity.

Another major conclusion from the graphic model is that in ecosystems with alternative stable states, the optimum shared use from a short-sighted economic point of view tends to be at the border of collapse of the ecosystem. In fact, ecosystem collapse is quite likely to occur in such situations, for a number of reasons. Stochastic variation in environmental conditions and imperfect information about the state of the ecosystem are major risk factors in the vicinity of the theoretical social optimum (Carpenter and others 1999). Importantly, our analyses also indicate a systematic bias away from the optimum toward increasing intensity of uses that affect the ecosystem quality. This bias is detrimental for social welfare and ecosystem quality in general, but its effects can be especially dramatic in ecosystems with alternative stability domains, where it easily

results in collapse of the system to a state with low overall social utility.

Toward Solution of the Power Bias

Our analysis of the power bias suggests that the differential organizational efficacy of Affectors relative to Enjoyers at mustering political power is a key problem. The ultimate roots of this differential ability lies not in corruption but in the superiority of Affectors in overcoming collective action problems. Enough is known now about what kinds of forces determine the relative efficacy of collective action that one could imagine designing policies that would level the collective-action organizational playing field across the two groups. An ideal solution would be a surrogate for a tax levied on the negative externalities that the Affectors load onto the Enjoyers through their relative efficiency at using the political system. The relative efficiency of the Affectors may have nothing at all to do with things like bribery, which capture the attention of the news media and the public imagination while generating general outrage. The real culprit is the slow, subtle "education" of the politicians and regulatory authorities imposed by steady daily contact with agents of the Affectors, who are better financed due to their superiority at mustering more resources per unit of stakeholder interest than the poorly organized Enjoyers.

For example, an association of real estate agents in the US can be much more effective with legislators than a collection of individual homeowners, because real estate agents must interact intensely with each other in order to match up buyers and sellers. This intense social networking of real estate agents produces collective action for other objectives such as "informing" legislators as a by-product of the microeconomics of their professional practice. In theory, some kind of tax could be levied on such effective associations in order to correct the resulting bias in pressure on politicians. Indeed, this is an example of a situation where the social capital created by intense, repeated networking (which is created, perhaps, as a by-product of particular business activities or cultural connections)—as has been stressed by writers such as Coleman (1990), Frank (1992), and Putnam (1995)—can lead to a loss for the economy as a whole. Indeed, a major cause of poor allocations such as those associated with the environmental problem is differential social capital across different stakeholders. Differential social capital leads to differential creation of political pressure, which in turn leads to an overall outcome that is not in the social interest. Once a correct diagnosis of the problem is made, remedies can be sought that bring the pressures on regulators and politicians into balance with the overall social interest. Our model is meant to illustrate this problem and to prompt discussion about mechanisms that might help balance equilibrium pressures on politicians and produce the overall social optimum.

Another logical approach to addressing the power bias and pushing the political balance back in the direction of the social welfare optimum would be to institutionalize the search for integrative solutions, as advocated by Mary Parker Follet (1924). Obviously, it is vital to integrate a broad form of benefit/cost analysis into public policy making ("broad" in the sense that a wider spectrum of values is considered, rather than just the narrower monetary values addressed by traditional benefit/cost analysis). Given that the current policy-making process tends to select a far worse alternative, this form of benefit/cost analysis seems preferable, despite the concerns expressed by critics such as Bromley (1990).

Bromley argues that efficiency measures used in benefit/cost analysis, such as the potential Pareto improvement criterion, do not "pass the test of consistency and coherence within economic theory, nor do such measures accord with what public decision makers seek in policy advice from economists" (Bromley 1990, p 86). If we assume that (a) our ecosystem is small relative to the economy as a whole, so that general equilibrium feedbacks may be ignored, and (b) income effects are small and may be ignored, then treating the objective of management of the lake ecosystem in the manner of a public utility manager gets around some of the criticisms of the operationalized utilitarianism that we are using here. See Bromley's critique of Harberger's (1974) attempt at an operationalized utilitarianism, and see Sen (1999) for the general difficulties in social choice and various approaches for dealing with them. However, Frank provides a spirited counterargument to some of these objections to benefit/cost analysis. For example, he argues that if a benefit/cost criterion "is employed as a policy for resolving large numbers of social decision, what is relevant is the pattern of decisions it produces" (Frank 1992, p 160, where "policy" and "pattern" are in italics). Frank's argument probably explains why there seems to be a rough consensus in how to deal with this problem in those small parts of the economy called "public utilities."

Hence, we take a benefit/cost posture in formulating the social objective here in order to get on with what we have to offer the reader. We assume that the RASP operates our "environmental public utility" to optimize the total value computed from willingness-to-pay (or willingness-to-accept) sched-

ules over all the services provided, in order to maximize the "size of the pie." Then we assume that the RASP redistributes the proceeds to different users to balance political pressures, such as, for example, delivering "basic needs" services to the poor at less than cost. We shall assume that the RASP effects this redistribution in such a way as not to distort any of the efficiency incentives to optimize the total value. For example, this could be accomplished by lump-sum subsidies to favored groups financed by revenues collected from efficient (nonlinear) pricing schedules (Wilson 1992) imposed on all services.

The Problem of Slow Social Dynamics

In the current analysis, we focused on mechanisms that determine the equilibrium use of ecosystems by society; however, in many situations, the trajectory toward that state of equilibrium is of particular interest because it may be very long. Indeed, it may take a long time before an environmental problem is even recognized, if it becomes recognized at all. In addition, the process of reaching a solution that reflects the balance of political power may be very slow. Since the cost for society of the many unsettled spillover problems is obviously huge, an understanding of the mechanisms governing these dynamics is essential if one wants to reduce the overall social cost of environmental problems. We address this dynamic multiproblem dimension in some detail in a separate paper (Scheffer and others forthcoming) and merely touch upon the main mechanisms of delay here.

Among the key factors determining the time needed to solve an environmental issue are social network structure, culture, and the role of particular key individuals. A first delay can be caused by the fact that in the early stages, many involved stakeholders may not even recognize that they have a stake (Westley and Vredenburg 1991). For instance, a chemical firm may be unaware that their operations will be impacted by the efforts of an environmental group concerned about the water quality in a nearby town. At the same time, many citizens may be unaware that their health has already been affected. Another significant delay may come in a later phase of the conflict at very high levels of organization. All stakeholders may find themselves entrenched in conflicting positions, making negotiations and coordination almost impossible (Lee 1993).

Social networks can play a decisive role in preventing or solving such conflicting gridlock situations if they represent repositories of social capital that can be mobilized. As Putnam and others have noted (Putnam 1993a, 1993b, 1995; Coleman 1990; Gray and others 2000; Nahapiet and Ghoshal 1998), social groups and systems vary enormously in the degree and kind of reciprocity that is built across and between formal organizations. Social capital represents a repository of good will, energy, and effort that can be mobilized rapidly around a given social cause (Fukuyama 1995). It is key in early domain formation and in breaking gridlock situations in later stages of domain formation. As Burt (1992; 1997) has pointed out, bridges across "structural holes" (linking two individuals whose primary networks are linked in no other way) represent the greatest increase in resources for the individual, but such links also bring new groups of stakeholders into exchange relationships and so may be of key importance.

Common culture is another crucial factor that can facilitate the process of finding a solution to an environmental problem. Particularly in the absence of a long history of reciprocity and the trust that it engenders, stakeholders often decide to enter into the initial reciprocities based on the belief that they share "representations, interpretations, and systems of meaning with the other party or parties" (Nahapiet and Ghoshal 1998). This, in part, explains the key role of "domain entrepreneurs" or visionary leaders in domain organization. They among others, have the ability to "tell a story" (create a structure of signification) that appeals to many different stakeholders (Gardner 1995) or tailor the story so as to secure the cooperation of key stakeholders (Westley 1992).

Furthermore, the relative strength of incentives of organized private profit-seeking corporate or commercial groups tends to be much greater. Hence, these groups are quicker to move toward opportunity than governments or regulators, as well as more diffuse and hence loosely organized groups. This imbalance can cause a disconnect between time scales of action on the part of, say, private profit agricultural firms acting as Affectors and sluggishly responding regulators or sluggishly responding, loosely organized Enjoyer groups. Correcting the response disconnect caused by disparities in incentive strength is part of the remedy needed to synchronize the response times of the different interest groups.

CONCLUSION

The analyses presented here are admittedly rather stylized and do not take much of the dazzling complexity of ecosystems and human societies into account. Nonetheless, they comprise a simple diagnosis of some of the major barriers to a sustainable and

fair shared use of ecosystem services and suggest some possibilities for their solution. A tendency toward suboptimal compromises, systematic bias in mustering political power, and slow social response to environmental problems emerge as key problems. Obviously, amelioration of the detrimental effect of common practices in ecosystem use on society and the environment require that strategies be tailored to the specific case. Our analysis suggests that such strategies would need to include at least the following key ingredients:

- A reliable model of the ecosystem's response to different forms of use
- An overview and valuation of the range of ecosystem services to society
- Correction of political bias due to differences in the organizational power of groups of stakeholders

In addition, smart facilitative management of the social process could help to reduce the delay in settling environmental disputes.

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Appendix 1 A Model for Ecosystems with Alternative Stable States

To analyze how socioeconomic systems interact with ecosystem dynamics, it is useful to capture the basic properties of the catastrophic response of ecosystems in a simple mathematical model. Although, on a high level of abstraction, lakes and drylands have some common properties, the actual mechanisms involved are quite different. Therefore, it is not possible to formulate a model that faithfully reflects the mechanisms operating in lakes, deserts, and other catastrophically responding ecosystems. Instead, we propose the following very simple model, which captures the catastrophic properties in a rather abstract way, describing the change over time of an unwanted ecosystem property x:

$$dx/dt = a - bx + rf(x) \qquad (1)$$

The parameter a represents stress imposed by human use, which promotes x. The remainder of the equation describes the internal dynamics: parameter b represents the rate at which x decays in the system, whereas r is the rate at which x recovers again as a function f of x. For lakes, one can think of x as nutrients suspended in phytoplankton, causing turbidity; of a as nutrient loading; of b as nutrient removal rate; and of r as internal nutrient recycling. For drylands, one may think of x as barren soil, of a as vegetation destruction, of b as recolonization of barren soil by plants, and of r as erosion by wind and runoff. This specific equation has also been proposed to mimic the dynamics of nutrient-loaded deep lakes (Carpenter and others 1999).

For $r = 0$, the model has a single equilibrium at $x = a/b$. The last term, however, can cause the existence of alternative stable states, for instance, if $f(x)$ is a function that increases steeply at a threshold (h), as in the case of the Hill function: $f(x) = x^p/(x^p + h^p)$, where the exponent p determines the steepness of the switch occurring around h. Notice that Eq. (1) can only have multiple stable states if the maximum $\{rf'(x)\} > b$.

Appendix 2 Optimizing Social Utility from Lake Use

Suppose the lake is affected by n Affectors, and each Affector i loads $a(i)$ nutrients into the lake. Then,

the dynamics of the lake in response to the Affectors action can be characterized by substituting a with $A = Sum[a(i)]$ in Eq. (1).

Now let the Affector utility be given by

$$UA = Sum[u(a(i), i)], \tag{2}$$

and the utility to Enjoyers be given by

$$UE = Sum[v(x, k)] \tag{3}$$

where u, v are concave functions, and where u is assumed to increase in $a(i)$, and v is assumed to decrease in x. Here the index k denotes the index of Enjoyer k, and the *Sum* in Eq. (3) is taken over all Enjoyers while the *Sum* in Eq. (2) is taken over all Affectors. Carpenter and others (1999) treat this problem in some detail.

In the "normative" case, where the future is weighted equal to the present (that is, there is no discounting), we would optimize welfare by solving the problem

$$Maximize\ \{UA + UE\}, \tag{4}$$

subject to the constraint that the ecosystem equilibrium state responds to the stress imposed by the total load A imposed by the Affectors. Note that we have assumed that once A is set and fixed, the ecosystem has relaxed to a steady state given by

$$dx/dt = 0 = A–bx + rf(x) \tag{5}$$

Figure 4 captures the solution to this kind of problem for the special case in which all Affectors and all Enjoyers are identical. In the figure, we plotted the value of the objective Eq. (4) on the vertical axis, A on the stress axis, and a desirable aspect of ecosystem state such as vegetation biomass on the third axis. Note that, since x represents an unwanted aspect (for example, turbidity or barren soil), x would increase from left to right along this axis.

In the special case where there are n identical Affectors and M identical Enjoyers, with utilities $u(a)$, $v(x)$ respectively the problem in Eqs. (4), (5) becomes

$$Maximize\ \{Nu(a) + Mv(x)\} \tag{4'}$$

subject to

$$dx/dt = 0 = Na–bx + rf(x) \tag{5'}$$

One can now imagine a management authority (compare the RASP) that defines the public interest as the total sum of Affector and Enjoyer utility as defined above. Suppose now that the authority does not know the law of motion Eq. (5′), which governs the ecosystem. Let the set S of steady states be defined by $S = \{(a, x)|0 = Na–bx + rf(x)\}$. It may then operate in an iterative way, simply responding to short-term changes in utility perceived by Affectors and Enjoyers in its attempts to regulate Na so as to increase $Nu(a) + Mv(x)$. For instance, if the authority starts at a very low level of "a" and gradually increases "a," continuously trading off the measured willingness to pay of Affectors against the measured value of quality loss from the Enjoyers, it will eventually reach a point indicated as "Optimum" in Figure 4b. Notice that this point does not have to be a global maximum. It may be a local maximum.

Appendix 3 Tax as a Way to Direct Society

Following Brock and Evans (1986), let a tax T on loadings be proposed as the regulatory instrument. The idea behind tax as an incentive is that given the tax rate T, Affectors will choose their loading "a" in such a way that they maximize their individual net benefit. Thus they solve:

$$Maximize\ \{u(a)–Ta\}, \tag{6}$$

which causes each Affector to choose $a(T)$ to solve (Figure 5),

$$u'(a) = T, \tag{7}$$

where $u'(a)$ is the derivative of u with respect to a, and we assume that there is a unique solution to Eq. (7) for each positive T. If a^* is the social optimum from the problem in Eqs. (4), (5), then we can choose $T = T^*$ by setting $T^* = u'(a^*)$ such that Eq. (7) yields the choice $a = a^*$. That is, just put $T^* = u'(a^*)$. This is the simplest story told in decentralized regulation of the negative externalities spilling over from the Affectors onto the Enjoyers.

Turn now to a slightly different type of tax-setting scheme that will serve as a foundation for the political economy model. Suppose a tax T is levied on Affectors' activities and the proceeds $a(T)T$ are redistributed in a lump sum to the Affectors in such a way that Eq. (7) still holds. This can happen, for example, when there are a large number of Affectors and each ignores his actions' impact on the total tax take. For each T, social welfare $W(T)$ is then given by

$$W(T) = Nu(a(T)) + Mv(x(T)), \tag{8}$$

where the ecosystem state experienced by the En-

joyers for given tax level, $x(T)$, is found by solving the ecosystem's equilibrium condition:

$$0 = Na(T) - bx + rf(x) \tag{9}$$

Notice that for a given $a(T)$ there may be more than one solution to Eq. (9), which depends on the history of the tax T. Suppose, for example, the tax is very low to start. Then $a(T)$ is initially very high, and there is only one solution, which is very high. As T increases, $a(T)$ falls and the ecosystem "slides" down the upper branch of the catastrophe fold until it reaches the lower "critical point", where there is a sharp drop in $x(T)$ that solves Eq. (9). For lower values of $a(T)$, there is now only one solution $x(T)$ to Eq. (9). We see that the tax T can be used to trace out the same hysteresis cycle depicted in Figure 4.

Now in the case where there is only one global welfare optimum (which is often not the case, as argued above), we can adjust T in the direction of increasing welfare on a slow scale of time relative to the time of relaxation of the ecosystem dynamics to a steady state given the loading by the hill-climbing procedure:

$$dT/dt = W'(T) = Nu'a'(T) + Mv'(x)x'(T)$$

$$= [(b - rf')u' + v'M]x', \tag{10}$$

where $'$ denotes derivative. The right hand side of Eq. (10) is obtained by differentiating equation (5) with respect to T at the solution $Na(T) = bx(T) - rf(x(T))$. Eq. (10) is intuitive. As the tax increases, $a(T)$ falls. Hence, $x(T)$ falls as long as the solution $x(T)$ is located on a rising part of the function $bx - rf(x)$, which will be the case when there is only one global welfare optimum (which we assume). Hence, Eq. (10) instructs the RASP to keep increasing the tax, provided that the marginal benefit to the Affectors is less than the marginal cost to the Enjoyers. Hence, we see that at a rest point of Eq. (10) we have:

$$0 = [(b - rf')u' + v'M], \tag{11}$$

provided that $x'(T)$ is not zero (which we assume). Notice that, indeed, Eq. (11) is the first-order necessary condition for a maximum for the welfare problem in Eqs. (4′), (5′). Thus, such an iterative tax setting procedure may result in reaching the welfare optimum. We shall think of Eq. (10) as a model for a regulator (a RASP) who is guided by normative analysis. This regulator adapts the instrument T toward the direction of increased welfare where all interests are equally weighted. Since Eq. (10) is a local hill-climbing procedure, it may get stuck on a local maximum when there are multiple local maxima.

Appendix 4 Collective Action Problems and their Effect on Political Power

Political-pressure supply functions may be derived as Nash equilibria from a noncooperative game model following Magee and others (1989, Appendix A.6.5, p 287). Their analysis suggests that the resources invested by an individual to exert political pressure depends positively on the expected effectiveness of its individual contribution and its interest at stake. For a very special case, Magee and others derive the following formulas for Nash equilibrium contributions for both sides of the conflict:

$$cx(T) = [A/N + B]\{U(0) - U(T)\}, \tag{12}$$

$$cy(T) = [C/M + D]\{V(T) - V(0)\}, \tag{13}$$

where $cx(T)$ and $cy(T)$ represent the pressure from individual Affectors and Enjoyers respectively against and in favor of raising the pollution tax from 0 to T;

$$U(T) = \textit{Affectors' utility} = u(a(T)) - a(T)T,$$

which is assumed to fall as T increases from zero; and $V(T) = \textit{Enjoyers' utility}$

$$= v(x(T)) + (1/M)(Na(T)T),$$

where $x(T)$ solves Eq. (9) for $a = a(T)$. (14)

In this model, the terms $[A/N + B]$ and $[C/M + D]$ represent the power attained by mustering collective effort for the Affectors and Enjoyers, respectively (Figure 6). The coefficients C, D for the Enjoyers (likewise A, B for the Affectors) capture Mancur Olson's notions of "perceived effectiveness" and "noticeability," respectively (Magee and others 1989). The perceived effectiveness (C) depends on the strength of beliefs on the power of the sum of contributions to move policy in the direction desired by the Enjoyers. The size of C would tend to increase along with the merit of the Enjoyers' case. Notice that the free-rider effect is captured by the term C/M, so that if each Enjoyer does not feel "noticeable" (that is, $D = 0$), then the contribution of each, $cy(T)$, will fall to zero as the number of Enjoyers (M) increases. Notice however, that when D is zero, the total contribution is C, so depending on how C depends on M, this may rise with M or fall with M when D is zero.

Let us give a brief explanation of the derivation of, for example, Eq. (12). Suppose the net utility that an individual i gets from giving contribution cx is $\{A\ log(Sum\ cx(j)) + Blog(cx(i))\}S(i) - cx(i)\}$, where the sum is over all j in i's lobbying group and $S(i)$ is the stake that i has in the outcome.

Notice that here A denotes a weight in the utility function, not the total load on the lake, as in Eq. (5) above. The formulation is just a mathematical metaphor (with a convenient illustrative functional form) to capture the idea that i believes that the total contributions $Sum\ cx(j)$ help to achieve the desired goal, the contribution gives i "warm glow" (Andreoni 1998), or i feels "noticeable" by the group if he/she does not contribute (Magee and others 1989, p 287), and that the value of the goal to i increases with his/her stake in the group goal $S(i)$. Maximize this function $w.r.t.\ cx(i)$ and solve to obtain Eq. (12) after putting the stake $S(i) = \{U(0) - U(T)\}$.

Recent work by Andreoni (1998) gives us another useful interpretation of the coefficients B and D besides that of Magee and others (1989). These terms are an attempt to capture the "warm glow" that the individual on each side of the conflict gets from giving and fighting for the cause that he/she believes in. See Andreoni's work (1998) for a view of group effort to promote a cause that focuses on developing a theory where people appear to be going against their individual self-interest in favor of the collective interests of their group. Andreoni's "supply functions" of the effort exerted by both sides of a conflict turn out to be closely related to those of Magee and others when terms playing similar roles to B and D are present.

Suppose that there is a regulator who continually adjusts the pollution tax T in such a way that the marginal pressures from the different interest groups is equalized. That is,

$$dT/dt = Y'(T) - X'(T), \tag{15}$$

where $Y(T) = Mcy(T) + Na(T)T$ equals total pressure supplied by Enjoyers in favor of the tax move from zero to T, and $X(T) = Ncx(T)$ equals the Affectors' pressure against the move. Notice that we have assumed that the proceeds of the taxes $Na(T)T$ effectively go to the Enjoyers. The conditions for a rest point of Eq. (15) are identical to the first-order conditions for a maximum of the weighted sum

$$(A + BN)u(a) + (C + DM)v(x), \quad \text{subject to } (a, x) \text{ in } S \tag{15$'$}$$

Thus, we need the power terms $(A/N + B)$ equal to $(C/M + D)$ in order for the system to deliver the same marginal conditions as maximization of the social objective

$$Nu(a) + Mv(x), \text{ subject to } (a, x) \text{ in } S \tag{16}$$

Any difference in power at mustering political pressure results in a deviation of the realized situation from welfare optimum, as discussed in the section on normative economics.

Generalizations of this simple model can be done to accommodate other, more realistic distribution formulas for the proceeds of the taxes. Indeed, one can imagine designing the distribution scheme to mobilize support for the program. For example, in practice, it is common to observe that it is a few Affectors who are at the root of the problem. This suggests that a redistribution scheme might be designed to mobilize most of the Affectors (who would like to run cleaner operations if they could afford it) against these few dirty players. One way of doing this that is consistent with a more complete concept of efficiency, which takes into account administrative costs and compliance costs of any regulatory scheme, is to use regulatory tiering (Brock and Evans 1985). This concept is based upon using empirical evidence on the distribution of problem sizes (which tends to be highly skewed, with a few of the players causing the bulk of the damages) to argue that overall efficiency is served by either exempting or lightly taxing most of the smaller problem causers. Basically, one uses data to estimate a "scaling law" of damages (Brock 1999). This scaling law is then used to design a tax schedule that taxes the big problem causers at a higher rate than the smallest ones. Indeed, the smallest problem causers may even be exempt from the tax. Regulatory tiering is attractive not only from the viewpoint of overall efficiency, but it also blunts political opposition emerging from small Affectors (of which there are typically many more than large Affectors), because they are exempted or, at most, lightly taxed. Hence, regulatory tiering is a valuable tool in putting together effective programs for environmental cleanup in practice. Indeed, there is evidence that the US political system acts "as if" it is tiering in many cases (Brock and Evans 1986). Notice that tiering can be predicted to blunt opposition from the Affector sector in political models such as the median voter model, as well as political models like ours that focus on balancing political pressures. A review of many kinds of political science models can be found in Magee and others (1989).

The graphic models that show how social welfare could be maximized (Figure 4) can be modified to produce graphs that show where the respective po-

litical power of the Affectors and the Enjoyers will be in balance (Figure 7). To see this, first consider the precise meaning of the figure in terms of our models. If one plots the ordered pair (Nu', Mv') on the surface of Figure 4b at each point (a, x) in the floor of the diagram, one gets the "flux" of local utility. That is, if one moves in the direction (da, dx) at (a, x) the flux of incremental social welfare is given by $Nu'da + Mv'dx = (Nu', Mv').(da, dx)$, where "." denotes "vector dot product". Thus, welfare increases locally when $Nu'da + Mv'dx = (Nu', Mv').(da, dx) > 0$ for a proposed policy move (da, dx). Since each level of a needs to be a steady state $x(a)$ of the ecosystem, we must restrain proposed differential policy movements (da, dx) to be compatible with the ecosystem equilibrium set S. That is,

$$0 = da - bdx(a) + f'(x(a))dx(a) \qquad (17)$$

In other words, the system guided by our RASP will move uphill in the direction of increasing social welfare (the plane) following the ecosystem equilibrium state.

Now consider the pair of socially optimal utility directional "arrows" (Nu', Mv'). Politics distorts these arrows by changing them into $([A/N + B]Nu', [C/M + D]Mv')$. A political force graph would thus be obtained by plotting $([A/N + B]Nu + [C/M + D]Mv)$ rather than $(Nu + Mv)$ as the objective function. This implies that differences in political power will tilt the depicted welfare plane, downweighting the interests of the less powerful group. Since, in the most egregious cases, there are typically a small number of highly organized large Affectors and a large number of tiny diffuse Enjoyers, we have C and D at approximately zero, so the objective function increases with stress (a) imposed by Affectors but becomes almost independent of the ecosystem state (x). Thus the hill-climbing political system will myopically move to higher stress levels, as it simply keeps looking for incremental moves $(da, dx(a))$ such that $([A/N + B]Nu', [C/M + D]Mv').(da, dx(a))$ is approximately equal to $([A/N + B]Nu', 0.Mv').(da, dx(a)) = ([A/N + B]Nu')da > 0$, and a just keeps tending to increase (Figure 7b).